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TOP MASS MEASUREMENT AT CDF

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Abstract

We report on recent measurements of the top quark mass using $t\bar{t}$ candidate events selected in $\simeq 320$ pb^{-1} of data from the "Run II" operation period of the Tevatron $p\bar{p}$ collider. More emphasis is given on the best single measurement to date ($M_{top} = 173.5^{+3.9}_{-3.8}$ GeV/c^2), provided by CDF using the "lepton plus jets" channel, where one W decays to a lepton-neutrino pair and the other into quarks (top quarks decay to Wb almost 100% of the time).

1 Introduction

The top quark is the heaviest fundamental particle of the Standard Model (SM): about 35 times larger than the next heaviest quark (b) in the theory. A precise measurement of its' mass (M_{top}) is important for SM's prediction power, because top quark loops affect many Electro Weak (EW) observables. The top mass is also linked with the mass of the W and the Higgs bosons via radiative corrections; a fact exploited by EW fits which use measured observables to simultaneously constrain the three masses assuming the Standard Model [1]. Since the Higgs eludes experimental observation, a precise measurement of the top quark and the W masses serve as a constraint to the Higgs mass.

Top quarks were first observed by the CDF and DØ collaborations in 1995 [2], in events produced at $p\bar{p}$ collisions of $\sqrt{s} = 1.8$ TeV during the "Run I" operation of the Fermilab Tevatron collider. The two experiments combined top mass measurements to find $M_{top} = 178.0 \pm 4.3$ GeV/c^2 [3]. In the current mode of operations ("Run II") the Tevatron provides $p\bar{p}$ collisions of $\sqrt{s} = 1.96$ TeV. At the time of this conference, it has delivered 1.3 fb^{-1} of integrated luminosity, with about 1 fb^{-1} recorded by each experiment (almost ten times the Run I data sample). The Tevatron plans to deliver 4 to 8 fb^{-1} per experiment, which aim to measure the top mass with an accuracy of ~ 2 GeV/c^2 each.

We present here four recent M_{top} measurements at CDF, obtained with datasets of 320 to 360 pb^{-1}. More emphasis is given on a novel method to attack the dominant systematic uncertainty of the measurement [4].

2 Top mass reconstruction

2.1 Event selection

Top quarks are mostly pair produced at the Tevatron, via $q\bar{q}$ annihilation ($\sim$ 85%) or gluon-gluon fusion, and they decay $\sim 100\%$ of the time to Wb, with the b quark hadronizing into a jet (j) of particles. Subsequently, W's decay to quarks ($q_1\,\bar{q}_2$) or to a lepton-neutrino ($\ell\nu$) pair and their decay mode sets the characteristics of the $t\bar{t}$ event. The most precise measurements are obtained in i) the *lepton plus jets* channel ("ℓ+*jets*"), where $t\bar{t} \to W^+\,b\,W^-\,\bar{b} \to b\,\bar{b}\,\ell\,\nu\,q_1\,\bar{q}_2$ (30% of $t\bar{t}$ decays, when $\ell \equiv e$ or μ), or ii) the *dilepton* channel, where $t\bar{t} \to W^+\,b\,W^-\,\bar{b} \to b\,\bar{b}\,\ell_1^{\pm}\,\ell_2^{\mp}\,\nu\,\bar{\nu}$ (5% of the time, when $\ell \equiv e$ or μ).

We select events containing a well identified and isolated electron or muon, large missing transverse energy from the neutrino(s) produced in the W decay(s), and jets with a multiplicity depending on the decay channel. All reconstructed objects are required to have high transverse energy (e.g., $E_T > 15$ GeV) [4]. In the dilepton channel, a second lepton is also requested; most commonly an e or μ candidate again, but sometimes we just ask for a well isolated and energetic track in order to recover some of the τ decays ("lepton plus track" selection) [5]. Dilepton and $\ell + jets$ samples are constructed to be mutually exclusive.

2.2 Measurement challenges

To reduce the combinatorial and physics background in the $\ell + jets$ channel, it is common to request at least one b-tagged jet, i.e., a jet identified as originating from a b quark, typically via the presence of a secondary vertex. Thus, if at least one jet is b-tagged, the possible jet-parton assignments are reduced from 12 to 6, and to just two if both b jets are tagged (the two W daughter jets are interchangeable in the reconstruction).

The largest systematic uncertainty in the M_{top} measurement is due to the uncertainty on the Jet Energy Scale (JES, i.e., the jet-to-parton energy translation). The original parton energy is estimated by correcting the jet for instrumental, radiation and fragmentation effects, with a $\sim 3\%$ uncertainty for high energy jets [6]. The novel top mass measurement we report here, uses the hadronic W decays in the $t\bar{t}$ data sample itself to further constrain the JES.

Even though statistically limited, the dilepton channel has a higher signal to background ratio due to the second lepton. No b tagging is then required. The two highest energy jets are assumed to be b jets and we are left with just two possible jet-parton assignments. Nevertheless, the measured missing energy is due to two neutrinos and we are faced with an under-constrained problem. We thus iterate over more assumptions about the event topology compared to the over-constrained case of the lepton plus jets channel. This complication results in a larger statistical uncertainty in this channel, but the smaller number of jets yields a smaller JES contribution to the systematic uncertainty.

2.3 Measurement methods

In template methods, we impose kinematic constraints on the event according to the $t\bar{t}$ decay hypothesis and for each possible topological configuration we compute an event χ^2 which takes into account the detector resolution and the W and top decay widths. We get the most probable reconstructed top mass per event and we compare the distribution with similarly obtained "template" p.d.f's from simulated background and signal events with known M_{top}. A likelihood minimization yields the M_{top} which best describes the measured distribution as an admixture of $t\bar{t}$ and background events.

In matrix-element methods, for each $t\bar{t}$ candidate event we calculate a likelihood, as a function of M_{top}, which is the differential probability that the measured quantities (4-momenta of reconstructed objects) correspond to a $t\bar{t}$ signal event. The likelihood is the convolution of the leading-order (LO) $t\bar{t}$ matrix element and detector resolution functions, integrated over all possible configurations. Similarly, we can also compute a likelihood for each event being background (e.g., W plus jets in the $\ell+jets$ case, or Drell-Yan for dilepton) and sum the likelihoods according to the relative abundance of each contribution. The product of the individual event likelihoods forms the joint likelihood of the data sample, which is fitted to yield the top mass measured from the sample.

3 Top mass measurements

3.1 The best single measurement

The most precise measurement is obtained with a 2-Dimensional template analysis of 318 pb^{-1} of $\ell + jets$ data [4]. This analysis uses the dijet mass from the in-situ $W \to jj$ decays to constrain the jet energy scale. Since the dijet mass is largely insensitive to the true top mass, we create separate templates of the reconstructed top and W masses in simulated events as a function of the true top mass and JES, respectively, and compare them with the data distributions.

In order to improve the statistical power of the method, four mutually exclusive subsamples are used, defined by the number of b-tagged jets and the jet E_T cuts. Sample "1-tag(T)" has one b-tag and $E_T > 15$ GeV for all jets, whereas "1-tag(L)" relaxes one jet's requirements to $8 < E_T < 15$ GeV. In each subsample we select the most "reasonable" $t\bar{t}$ candidates by applying a cut on the χ^2 mentioned in Section 2.3. Figure 1 shows the reconstructed top mass in the data, with the best fits from the simulated templates overlaid. Similar plots are obtained for the dijet mass. A two-dimensional likelihood fit yields both the measured top mass and the JES shift (in σ's) from the a-priori estimate via independent means [6]. We get $M_{top} = 173.5^{+3.7}_{-3.6}$ (stat.) GeV/c^2, were the uncertainty is statistical and incorporates the JES contribution (~ 2.5 GeV/c^2, to be compared to a 3.1 GeV/c^2 contribution in the 1-D template method, where the hadronic W decays are not used to constrain the JES).

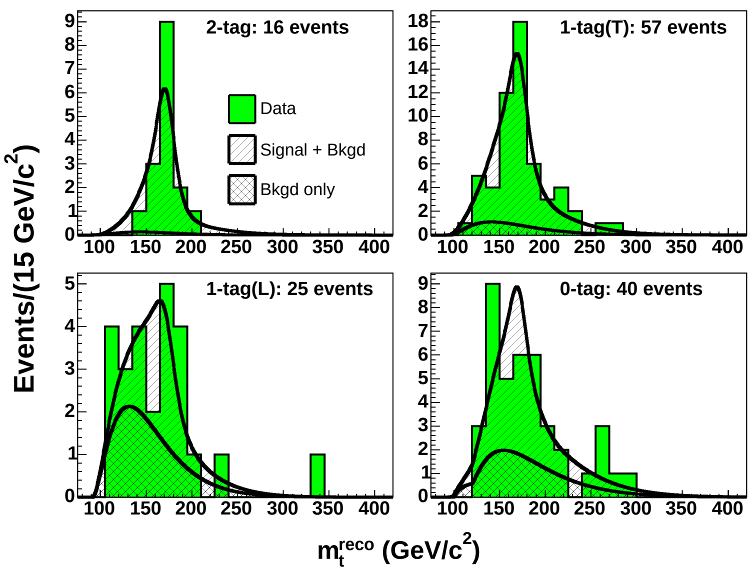

Figure 1: *Reconstructed top mass in the four data subsamples (solid), with the best fits from the simulated templates overlaid (hatched). The contribution of background events is also shown (double-hatched).*

The systematic uncertainties not included in the JES are small (1.3 GeV/c^2), resulting in $M_{top} = 173.5^{+3.9}_{-3.8}$ GeV/c^2.

3.2 Other measurements

Matrix-element methods are used on both the ℓ+*jets* and the dilepton channels, and are proved to be very powerful statistically. We select events with exactly four or exactly two energetic jets for the $\ell + jets$ and the dilepton channels, respectively; this way, NLO effects are minimized when comparing the data with the LO matrix element for the $t\bar{t}$ production and decay. With 63 $\ell + jets$ events containing at least one b-tagged jet each, a matrix-element analysis measures $M_{top} = 173.2^{+2.6}_{-2.4}$ (stat.) ± 3.2 (syst.) $= 173.2^{+4.1}_{-4.0}$ GeV/c^2, where the JES contributes a 3 GeV/c^2 systematic uncertainty [4]. In the dilepton channel, 33 events reconstructed in 340 pb-1 of data yield $M_{top} = 165.3 \pm 6.3$ (stat.) ± 3.6 (syst.) GeV/c^2 (with a 2.6 GeV/c^2 systematic uncertainty due to the JES) [7].

The most precise measurement with a template method in the dilepton channel comes from the Neutrino Weighting Algorithm; for each top mas hypothesis we integrate over all possible neutrino η's and calculate the probability that the measured missing energy is matched. The most probable top mass from each event serves as input to the template methodology (Section2.3). With 45 "lepton plus track" events reconstructed in 360 pb^{-1} of data, this method gives $M_{top} = 170.7^{+6.9}_{-6.5}$ (stat.) ± 4.6 (syst.) GeV/c^2, where the JES contributes a 3.4 GeV/c^2 systematic uncertainty [7]. Combining the dilepton measurements at CDF we get $M_{top} = 167.9 \pm 5\ 2$ (stat.) ± 3.7 (syst.) GeV/c^2 [7].

4 Summary and outlook

The top mass measurement is entering a precision phase. CDF has provided the single best measurement to date ($M_{top} = 173.5^{+3.9}_{-3.8}$ GeV/c^2) by using a 2-dimensional template method which constraints the jet energy scale by using the dijet mass from the in-situ hadronic W decays in lepton plus jets $t\bar{t}$ candidate events. The jet energy scale is the biggest contributor to the M_{top} systematic uncertainty: ~ 2.5 GeV/c^2 with the 320 pb^{-1} data sample of this measurement, but it's expected to contribute ~ 1.5 (1) GeV/c^2 when 2 (4) fb^{-1} are collected and analyzed.

By using exclusive datasets and combining the best measurement from each channel, a preliminary Tevatron average ($M_{top} = 172.7 \pm 2.9$ GeV/c^2) was obtained in the summer of 2005 [8]. This is already a 1.7% measurement.

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